(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 708 389 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
24.04.1996 Bulletin 1996/17

(51) Int. Cl.^{6}: **G05B 9/02**, F16K 37/00

(21) Application number: **95306546.3**

(22) Date of filing: **18.09.1995**

(84) Designated Contracting States:
DE FR GB

(30) Priority: **18.10.1994 US 324653**

(71) Applicant: **NELES-JAMESBURY OY**
FIN-00881 Helsinki (FI)

(72) Inventor: **Pyötsiä, Jouni**
F-00930 Helsinki (FR)

(74) Representative: **Gilmour, David Cedric Franklyn et al**
POTTS, KERR & CO.
15 Hamilton Square
Birkenhead Merseyside L41 6BR (GB)

(54) Method and apparatus for detecting a fault of a control valve assembly in a control loop

(57) A method and apparatus for detecting a fault of an automatically operated control valve assembly. Data consisting of several values of the control signal (i) and corresponding values of the position (h) of the control valve is measured and recorded. A mathematical model for the control valve assembly is defined. The mathematical model is fitted to the data measured from the control signal (i) and the position (h) of the control valve. At least one critical parameter for each component of the valve assembly, that is the valve (2) itself, the actuator (3) and the positioner (5), is chosen. The values and changes of the critical parameters are computed from the mathematical model fitted to the measured data. The component in which the fault is located is detected on the basis of the computed values of the critical parameters.

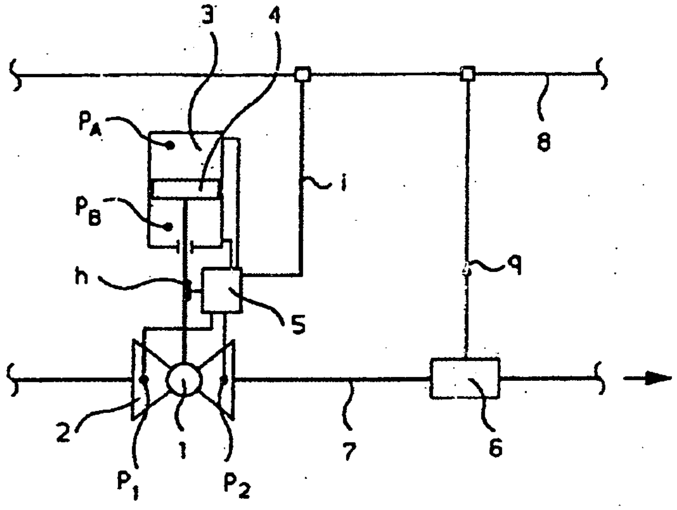


Fig. 1

EP 0 708 389 A1

Printed by Rank Xerox (UK) Business Services
2.11 3/3.4

Description

This invention relates to a method for detecting a fault of an automatically operated control valve assembly in a control loop so that data consisting of several values of the control signal and corresponding values of the position of the control valve is measured and recorded. The invention also relates to an apparatus for detecting a fault in an automaticly operated control valve assembly, the valve assembly including a control valve, an actuator and a digital positioner, as well as means for measuring, transferring, recording and processing data.

The importance of advance maintenance of control valves has further increased when it is desired to decrease maintenance costs, to increase safety and to have the processes functioning accurately while saving energy and reducing waste. New positioners based on digital technology give better possibilities for this. On the other hand, the development of new data transfer buses gives better possibilities for transferring diagnostic data from the field device to the automation system and for transmitting measurement data from sensors outside the control valve to the control valve.

A control valve and its operation is known and need not be described here in detail. A quarter turn valve can be for instance a ball valve or a butterfly valve. Examples of a ball valve are disclosed for instance in US patent 4 747 578. A control valve is actuated by means of an actuator which turns the stem of the closure member between open and closed positions. An actuator can be operated by means of a cylinder-piston device which in turn is regulated by means of a regulation valve. A valve positioner operates the actuator in response to a control signal.

Various systems have been developed for the diagnostics of control valves, and these systems can be used for measuring and testing the valves in order to detect faulted operation. US patents 5 272 647, 5 233 512, 4 509 110, 4 213 175 and 5 129 418 all describe various diagnostic arrangements. However, they do not enable the location of the fault to be detected.

Some systems, such as the one described in US patent 5 197 328, even make it possible to locate the reason of the faulted operation, but it requires a complicated measurement arrangement and a lot of measurement data from the various components of the control valve assembly, that is from the valve itself, the actuator and the positioner.

The object of the present invention is to provide a method and an apparatus which are able to independently draw conclusions of faulted operation and to locate the faulted component by means of a simple measurement arrangement and by using a mathematical model of a control valve assembly and a data transfer bus.

The method of the invention is characterized in that

a mathematical model for the control valve assembly is defined,

the mathematical model is fitted to the data measured from the control signal and the position of the control valve,

at least one critical parameter for each component of the valve assembly, that is the valve itself, the actuator and the positioner, is chosen,

the values and changes of the critical parameters are computed from the mathematical model fitted to the measured data,

the component in which the fault is located is detected on the basis of the computed values of the critical parameters.

The apparatus of the invention is characterized in that the means for processing the data includes a program

to fit a mathematical model to the data measured from the control signal and the position of the control valve,

to compute the values and changes of at least one critical parameter for each component of the valve assembly, that is the valve itself, the actuator and the positioner, from the mathematical model fitted to the measured data, and

to detect the faulted component of the control valve assembly on the basis of the computed values of the critical parameters.

The method is based on identification of certain critical parameters of a mathematical model defining the dynamics and statics of a control valve, and on following the changes in these parameters. This makes is possible to detect and to conclude the faulted point. The advantage of the method is that the faulted operation and the location of the faulted component can be defined for instance by means of the control signal and the valve position data only.

In order to detect erosion damage of the closure member or possible blockage in the valve body, it is necessary in addition to measure the pressure over the valve and to obtain data of the volume flow through the valve. This data can best be obtained through a data transfer bus from the measurement sensors.

The invention and its details are further described with reference to the accompanying drawings in which

Fig. 1 shows schematically a measuring arrangement for the diagnostic system of an entire control valve assembly,
Fig. 2 shows a graph illustrating the correspondence between simulation carried out by means of identified parameters and measured values,
Fig. 3 shows graphically the relative change of the capacity coefficient of an eroded valve, and
Fig. 4 shows graphically the decrease of the relative capacity coefficient of a blocked valve.

The measuring arrangement of Fig. 1 makes it possible to detect and locate a fault affecting the dynamics of a control valve assembly and to detect possible erosion of a closure member of the valve or blockage of the valve body.

In Fig. 1, the closure member 1 of a valve 2 is provided with an actuator 3 which operates the valve by means of a cylinder 4. A digital positioner 5 is connected to the actuator. A volume flow sensor 6 is connected between a discharge pipe 7 and a field bus 8.

In order to define the dynamic operation of the valve, only data about the control signal i and the valve position h from the position transmitter is required. In addition, the detection of erosion of the closure member 1 and blockage of the valve body 2 requires pressure measurements p_1, p_2 for instance from the valve body 2 and flow data q from the volume flow sensor 6. The volume flow data q can be transmitted to the positioner 5 of the control valve for instance by means of the digital field bus 8. In this case, also the desired value of the control signal i is transmitted to the positioner 5 of the control valve by means of the digital field bus 8.

The locating of a fault affecting the dynamics of a control valve assembly will be described in the following.

The following equation can be found for the mathematical model of a quarter turn control valve provided with a cylinder-piston operated actuator:

$$\left(m_{red}\cdot\frac{dx}{d\psi}+J\cdot b(\psi)\right)\frac{d^2\psi}{dt^2}+m_{red}\cdot\frac{d^2x}{d\psi^2}\left(\frac{d\psi}{dt}\right)^2 + \left(f_m\cdot\frac{dx}{d\psi}+f_v\cdot b(\psi)\right)\frac{d\psi}{dt}+b(\psi)\cdot M_\mu - F_m(p_A,p_B)=0 \qquad (1)$$

where

x = distance travelled by the actuator piston
ψ = rotational angle of the valve
t = time
m_{red} = reduced mass of the actuator piston
J = combined inertia moment of the valve and the actuator
b = actuator coefficient
M_μ = friction moment of the valve
f_m = attenuation coefficient of the actuator
f_v = attenuation coefficient of the valve
F_m = force applied to the actuator piston
p_A, p_B = pressure levels of the actuator cylinder

Even if a quarter turn valve is discussed in this case, the method can be applied correspondingly to linear valves.

The movement of the actuator is controlled by means of the pressure levels of the cylinder which in the equation (1) are indicated by p_A, p_B. These can be computed by means of the following mathematical model defining the pressure level of the cylinder:

$$p_A = \Psi\,(k,\, V_A,\, T_a,\, m_a,\, A_A,\, x,\, R,\, M) \qquad (2)$$

$$P_B = \Theta\,(k,\, V_B,\, m_B,\, m_b,\, A_B,\, x,\, R,\, M) \qquad (3)$$

where

Ψ, Θ = mathematical functions
k = polytropic constant
V_A, V_B = air volumes of the actuator cylinder
m_B = mass of the air in the cylinder
T_a = temperature of the air entering the cylinder
m_a = mass flow of the air entering the cylinder
m_b = mass flow of the air leaving the cylinder
A_A, A_B = piston areas of the actuator
x = the same as in equation (1)
R = gas constant
M = mole mass

The pressure levels are controlled by means of the mass flow entering and leaving the cylinder. The entering and leaving mass flows depend on the respective cross-sectional flow area of the regulating valve of the positioner. The cross-sectional flow area depends on the position of the spool or, in a poppet type construction, on the position of the seat of the regulating valve. Mathematically this can be written for one half of the actuator cylinder in the form:

$$m_a \approx f(A_a) \approx g(e) \qquad (4)$$

where

A_a = the effective cross-sectional flow area of one half A of the regulating valve
e = the position of the spool or the seat

An accurate mathematical model can be found for the functions f and g appearing in the equation.

The position of the spool or the seat of the regulating valve can be computed from the mathematical model of the regulation of the regulating valve. The following mathematical connection can be found for the conventional positioners based on the feedback of the valve position:

$$e = \Phi(k_p, i, h) \qquad (5)$$

where

Φ = mathematical function
k_p = gain of the positioner
i = control signal
h = opening of the control valve

The following is a decription of the method of locating the fault.

The method according to the invention is based on the identification of the critical parameters describing the various components of a control valve assemby, such as the positioner, the actuator and the valve itself. Identification is a method where the parameters of a mathematical model of a device are found by means of actual measurement data by fitting the model to the measured data. The greater the number of the parameters to be identified, the more difficult the identification in practice is. The measurement data is obtained either by means of a separate test or tests or merely by following the dynamic operation of the device during the operation process.

In the method of the invention, measurement data is required only from the position of the valve and from the control signal. If measurement data is collected also from the cylinder pressures of the actuator, it will assist in finding the location of the fault.

The method is based on the fact that a test or a series of tests is carried out for instance by means of a digital positioner in order to collect the necessary measurement data. The measurement data can also be collected directly from a control valve assembly in operation when the control signal coming from the regulator to the valve changes sufficiently. The data measured is recorded in the memory of the positioner for the identification.

The critical parameter or parameters for each component of a control valve assembly, that is the positioner, the actuator and the valve itself, are identified from the above mathematical model by means of the measurement data. The critical parameters describing the operations of each component are chosen as the parameters to be identified.

The operation of a positioner is best described for instance by the gain k_p of the positioner. The extent of the output moment of an actuator again is expressed for instance by the actuator coefficient b. A mechanical fault of a valve is usually disclosed by friction so that for instance the friction load M_μ is the most suitable parameter for identification.

Fig. 2 illustrates the correspondence between simulation carried out with the identified parameters and the measured values. The curves show i/h as a function of time. Curve 11 presents input signal, curve 12 simulation and curve 13 measured data.

Fig. 2 shows measurement data produced by means of a sinusoidal control signal. The parameters of a simulating model made from a mathematical model were identified by means of the measurement data. The simulation carried out with the identified parameters corresponded well to the measured values as can be seen from Fig. 2.

The method can be made more accurate by measuring also the pressure levels p_A, p_B of the cylinder. Due to the increased measurement data, for instance the cross-sectional flow area of the regulating valve of the positioner can be identified. This can be further used for detecting for instance dirt in the regulating valve.

By following the change of the identified critical parameters, it is possible to watch by means of a conclusion program the change of a parameter describing the operation of each component. If changes or sliding as a function of time takes place in a certain parameter, it shows that essential changes take place in the operation of the component. The direction of the change shows if the operation of the control valve is going towards better or worse. If the value of the critical parameter of a certain component has changed sufficiently to a certain direction, it discloses the faulted component. In the concluding, it is also possible to use a diagram illustrating the change of an error between the control signal and the position of the control valve. A change in this diagram discloses if the error of a control valve is increasing or decreasing.

By means of the above method, it is possible by utilizing a simple conclusion program to automatically seek in which component of the control valve assembly operational changes take place and which component probably is the reason for instance to impaired control accuracy.

The finding of erosion and blockage of a control valve will be described in the following.

The method is based on reviewing the characteristic curve of a valve mounted in a process piping system. In this method, for instance the volume flow through the valve has to be measured by means of a volume flow sensor, in addition to the measuring of the pressure by means of pressure sensors in the valve. This data can best be made available for instance by means of a field bus.

The detection of eroding and blockage of a control valve is based for instance on pressure data measured in the valve body and volume flow data obtained for instance by means of a field bus which are utilized for instance in a digital positioner or in auxiliary equipment where the computing and analyzing take place.

Fig. 1 shows an example where position and pressure sensors connected to the valve body 1 are used for defining the opening h of the valve and the incoming pressure p_1 and discharge pressure p_2. This data combined with the flow quantity q obtained from the volume flow sensor 6 makes it possible to compute the set capacity coefficient Cv of a control valve.

The data obtained from the measurements is collected for instance in the digital positioner 5 where the capacity coefficient of the said valve can be computed by means of the equations set forth in standard IEC534 (ISAS75).

The results obtained are compared to a capacity coefficient measured in a laboratory. From the change in the capacity coefficient, it can be seen if the valve is eroding or being blocked. If there is erosion in the valve, the capacity coefficient tends to increase, particularly with small openings. Correspondingly, blockage will cause the capacity coefficient to decrease, particularly with greater openings.

A fault in an eroded or in a blocked valve will best be detected by following the change in the capacity coefficient of the valve in relation to the original capacity coefficient.

Fig. 3 shows the relative change of the capacity coefficient of an eroded valve as a function of the opening angle α. As can be seen from Fig. 3, the eroding can be very clearly seen, particularly at small opening angles. By following the relative change shown in Fig. 3 for instance by means of a digital positioner, it is possible to conclude the speed of erosion of the valve and to decide when the valve has to be changed at the latest.

Fig. 4 shows the change of the capacity coefficient of a blocked valve in relation to the original capacity coefficient. As can be seen from Fig. 4, the reduction of the capacity coefficient, caused by blockage, can in the measured case be seen more clearly at greater opening angles.

The invention is not restricted to the above embodiments but it may vary within the scope of the claims. Instead of a rotational valve, the control valve can be also a linear valve. The actuator need not be cylinder-piston operated, it can be for instance electrically operated.

Claims

1. A method for detecting a fault of an automatically operated control valve assembly in a control loop so that data consisting of several values of the control signal (i) and corresponding values of the position (h) of the control valve is measured and recorded, **characterized** in that

   a mathematical model for the control valve assembly is defined,

   the mathematical model is fitted to the data measured from the control signal (i) and the position (h) of the control valve,

   at least one critical parameter for each component of the valve assembly, that is the valve (2) itself, the actuator (3) and the positioner (5), is chosen,

   the values and changes of the critical parameters are computed from the mathematical model fitted to the measured data,

   the component in which the fault is located is detected on the basis of the computed values of the critical parameters.

2. A method according to claim 1, for detecting a fault in a control valve assembly, provided with a cylinder-piston operated actuator (3), **characterized** in that the measured data includes data also from the actuator cylinder pressures (p_A, p_B).

3. A method according to claim 1, **characterized** in that the measured data includes data also from the incoming and discharge pressures (p_1, p_2) of the control valve and from the volume flow (q) through the control valve, and possible erosion of the closure member of the control valve or possible blockage of the valve body is detected.

4. A method according to claim 1, **characterized** in that the gain (k_p) of the positioner is used as the critical parameter for the positioner.

5. A method according to claim 1, **characterized** in that the actuator coefficient (b) is used as the critical parameter for the actuator.

6. A method according to claim 1, **characterrized** in that the friction load (M_μ) of the control valve is used as the critical parameter for the control valve.

7. A method according to claim 1, for detecting a fault in a control valve assembly, including a quarter turn valve (2) and a cylider-piston operated actuator (3), **characterized** in that the following equation is used as the mathematical model:

$$(m_{red} \cdot \frac{dx}{d\psi} + J \cdot b(\psi))\frac{d^2\psi}{dt^2} + m_{red} \cdot \frac{d^2x}{d\psi^2}(\frac{d\psi}{dt})^2 + (f_m \cdot \frac{dx}{d\psi} + f_v \cdot b(\psi))\frac{d\psi}{dt} + b(\psi) \cdot M_\mu - F_m(p_A,p_B) = 0 \qquad (1)$$

where

x = distance travelled by the actuator
ψ = rotational angle of the valve
t = time
m_{red} = reduced mass of the actuator
J = combined inertia moment of the valve and the actuator
b = actuator coefficient
M_μ = friction moment of the valve
f_m = attenuation coefficient of the actuator
f_v = attenuation coefficient of the valve
F_m = force applied to the actuator piston
p_A, p_B = pressure levels of the actuator cylinder

8. A method according to claim 7, **characterized** in that the pressure levels of the actuator cylinder are computed by means of the following mathematical model:

$$p_A = \Psi\ (k, V_A, T_a, m_a, A_A, x, R, M) \qquad (2)$$

$$P_B = \Theta\ (k, V_B, m_B, m_b, A_B, x, R, M) \qquad (3)$$

where

Ψ, Θ = mathematical functions
k = polytropic constant
V_A, V_B = air volumes of the actuator cylinder
m_B = mass of the air in the cylinder
T_a = temperature of the air entering the cylinder
m_a = mass flow of the air entering the cylinder
m_b = mass flow of the air leaving the cylinder
A_A, A_B = piston areas of the actuator
x = the same as in equation (1)
R = gas constant
M = mole mass

9. A method according to claim 8, **characterized** in that the mass flow of the air entering one half of the actuator cylinder is computed from the following:

$$m_a \approx f(A_a) \approx g(e) \qquad (4)$$

where

f, g = mathematifal functions
A_a = the effective cross-sectional flow area of one half A of the regulating valve
e = the position of the spool or the poppet

10. A method according to claim 9, **characterized** in that the position of the spool or the poppet of the regulating valve of the positioner is computed from the following:

$$e = \Phi(k_p, i, h) \qquad (5)$$

where

Φ = mathematical function
k_p = gain of the positioner
i = control signal
h = opening of the control valve

11. An apparatus for detecting a fault in an automaticlly operated control valve assembly, the valve assembly including a control valve (2), an actuator (3) and a digital positioner (5), as well as means for measuring, transferring, recording and processing data consisting of several values of the control signal (i) and corresponding values of the position (h) of the control valve, **characterized** in that the means for processing the data includes a program

to fit a mathematical model to the data measured from the control signal (i) and the position (h) of the control valve,

to compute the values and changes of at least one critical parameter for each component of the valve assembly, that is the valve (2) itself, the actuator (3) and the positioner (5), from the mathematical model fitted to the measured data, and

to detect the faulted component of the control valve assembly on the basis of the computed values of the critical parameters.

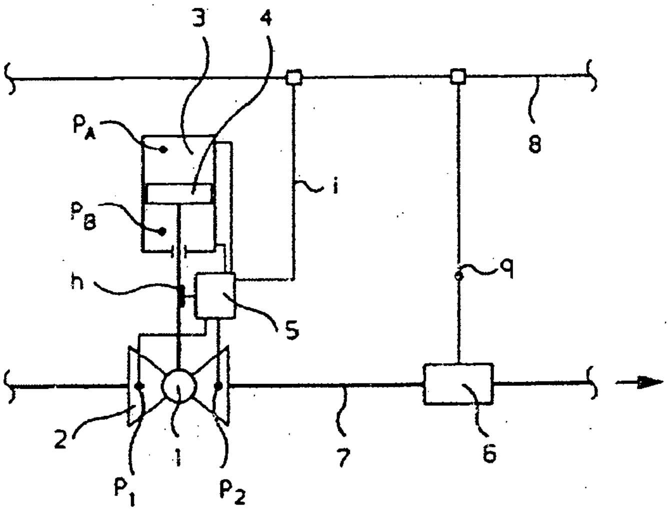


Fig. 1

Fig. 2

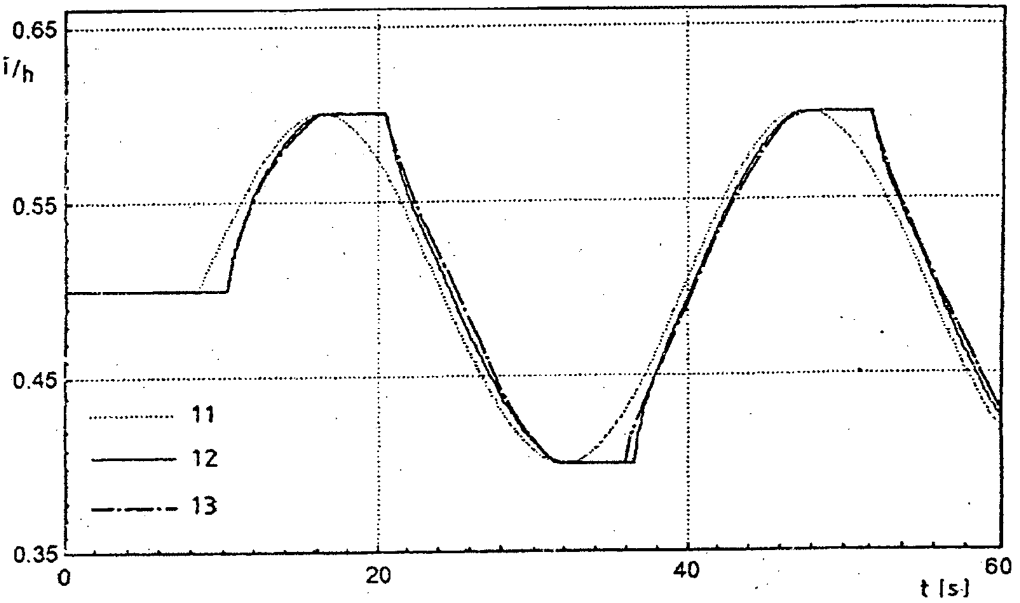
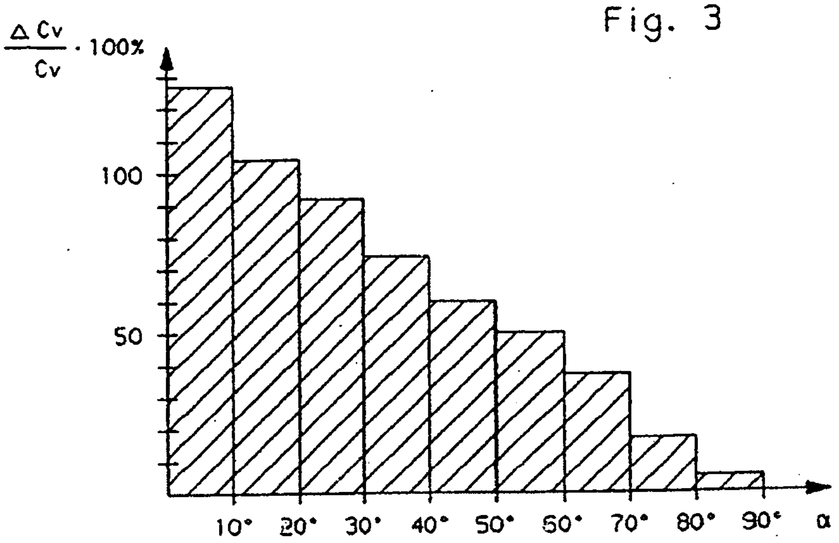
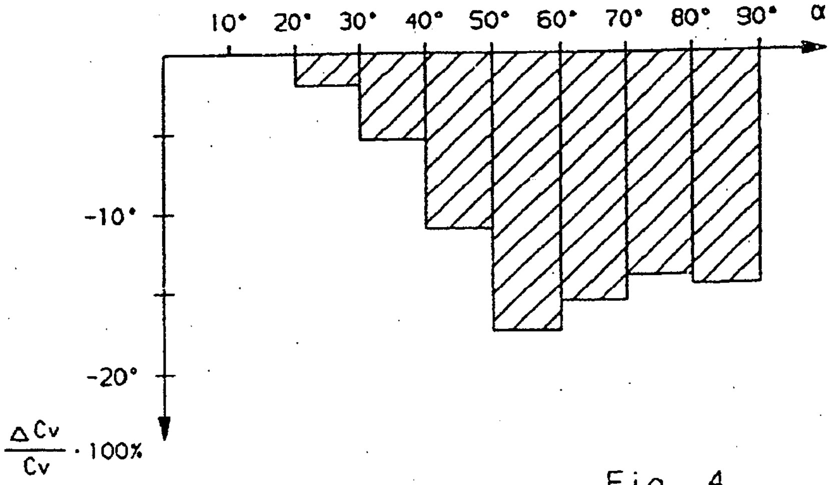


Fig. 3



$\frac{\Delta Cv}{Cv} \cdot 100\%$
100
50
10°
20°
30°
40°
50°
60°
70°
80°
90°
α



10°
20°
30°
40°
50°
60°
70°
80°
90°
α
-10°
-20°
$\frac{\Delta Cv}{Cv} \cdot 100\%$

Fig. 4

European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 30 6546

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Y	EP-A-0 315 391 (WESTINGHOUSE) * page 4, line 56 - page 5, line 10 * * page 6, line 32 - page 8, line 51; figures 1-3,6 * ---	1-3,11	G05B9/02 F16K37/00
Y	AUTOMATISIERUNGSTECHNISCHE PRAXIS - ATP, vol. 34, no. 10, October 1992 MUNCHEN DE, pages 577-581, J. QUADE 'Fehlerdiagnose an Feldbussystemen' * page 578, left column, line 13 - line 32 * ---	1-3,11	
Y	US-A-4 029 122 (K.O. JAEGTNES) * claim 1; figure 1 * ---	2	
A	PATENT ABSTRACTS OF JAPAN vol. 7 no. 241 (P-232) ,26 October 1983 & JP-A-58 129315 (MITSUBISHI) 2 August 1983, * abstract * ---	1,11	
A	EP-A-0 287 299 (ELECTRIC POWER RESEARCH INSTITUTE) * column 3, line 30 - column 4, line 3 * * column 5, line 9 - line 42; figures 1-4 * ---	1,11	TECHNICAL FIELDS SEARCHED (Int.Cl.6) G05B F16K G01D
A,D	US-A-5 233 512 (GUTZ ET AL.) * the whole document * -----	1,11	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	22 January 1996	Goetz, P

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)